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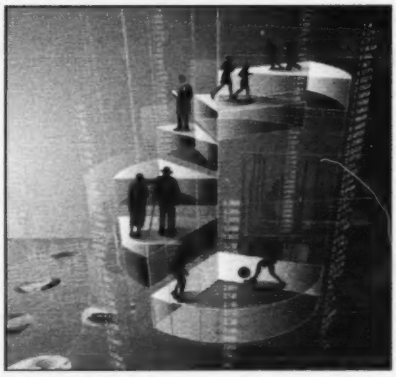

by Suzy L. Wong

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Grip strength reference values for Canadians aged 6 to 79: Canadian Health Measures Survey, 2007 to 2013

by Suzy L. Wong

Abstract

Background: Grip strength is a measure of overall muscular strength and has been associated with disability, morbidity and mortality. Normative data are used to interpret an individual's grip strength measurements, but Canadian reference values are not available for a wide age range.

Data and methods: The data pertain to 11,108 respondents aged 6 to 79 to the 2007-to-2013 Canadian Health Measures Survey, whose right-hand and left-hand grip strength were measured with a handgrip dynamometer. Quantile regression was used to develop reference equations for males and females for maximum, right-hand and left-hand grip strength for selected percentiles as a function of age, height and weight.

Results: Reference values for grip strength increased through childhood and adolescence, peaked around age 40, and then declined. Reference values were higher for males than for females; differences between the sexes were smaller during childhood than in adolescence and adulthood. Differences between reference values for maximum, right-hand and left-hand grip strength varied by age and sex.

Interpretation: Based on a large, healthy, nationally representative sample, reference equations were developed for grip strength of Canadians from childhood to older adulthood. These equations can be used to determine the reference values that correspond to an individual of a given age, sex, height and weight.

Keywords: Dynamometer, handgrip strength, muscular strength, normative data, norms, reference equations

Grip strength is a simple, fast and reliable measure of the maximum voluntary force of the hand.[1,2] It is used to assess hand injuries[2] and is an indicator of overall muscular strength, nutritional status, muscle mass and walking performance.[1] Grip strength is also a marker of hypertension and type 2 diabetes[3] and a predictor of all-cause, cardiovascular and non-cardiovascular mortality, heart attack, stroke,[4] disability, and surgical complications.[5]

Based on normative data, the grip strength of an individual can be assessed relative to a reference population. Grip strength norms, or reference values, have been established to evaluate hand injuries, set treatment goals, evaluate surgical outcomes, and assess a patient's ability to return to employment.[6] Such norms are presented separately for each hand— left and right, or dominant and non-dominant. More recently, as interest in grip strength has extended beyond the evaluation of hand function to overall muscular strength, nutritional status and disability,[1,5] norms have been presented as the maximum grip strength measured from either hand.[1]

Grip strength norms are stratified by age and sex; height and weight may also be taken into account to provide more refined norms.[1] Generally, the reference population is healthy, although norms have been published for specific populations, such as older adults with chronic conditions.[7]

Numerous studies have provided grip strength norms, but some studies were based on samples that were small and/or not nationally representative.[1] In addition, most studies focussed on adults, particularly older adults; relatively few examined childhood, adolescence and early adulthood.[1]

National variations in grip strength suggest that norms developed for one country are not applicable to other countries.[2] In Canada, the grip strength of people aged 15 to 69 has been interpreted using the Canadian Physical Activity, Fitness and Lifestyle Approach (CPAFLA) musculoskeletal fitness norms, which categorize total grip strength values into five Health Benefit Ratings ranging from "Excellent" to "Needs Improvement."[8] However, the methods and reference population used to derive the CPAFLA norms are not documented. Further, the use of total grip strength (sum of right- and left-hand grip strength) is inconsistent with other norms and does not allow comparisons with previous studies.

The purpose of this analysis was to use data from the 2007-to-2013 Canadian Health Measures Survey to develop reference equations for maximum, right-hand and left-hand grip strength for Canadians aged 6 to79, based on a healthy, nationally representative population. These equations can be used to determine reference values against which to assess an individual's grip strength.

Data and methods

Canadian Health Measures Survey

Data are from the first three cycles of the Canadian Health Measures Survey (CHMS), an ongoing survey conducted by Statistics Canada in partnership with the Public Health Agency of Canada and Health Canada. The CHMS provides comprehensive direct health measures at the national level for the household

Authors: Suzy L. Wong (suzy.wong@canada.ca) is with the Health Analysis Division at Statistics Canada, Ottawa, Ontario.

population. It involves an in-person household interview and a subsequent visit to a mobile examination centre (MEC). The household interview gathers general demographic and socioeconomic data and detailed health, nutrition and lifestyle information. At the MEC, direct physical measurements are taken, including grip strength, height and weight. Ethics approval for the CHMS was obtained from Health Canada's Research Ethics Board.

Cycle 1 collected information from respondents aged 6 to 79 from March 2007 through February 2009. Cycles 2 and 3 collected information from respondents aged 3 to 79 from August 2009 through November 2011, and from January 2012 through December 2013, respectively. For the three cycles combined, 16,606 respondents completed the MEC component. After adjustments for the sampling strategy, the final response rate for 6- to 79-year-olds was 52.9%. Details about the survey are available at www.statcan.gc.ca/chms.

Grip strength measurement

Grip strength was measured using handgrip dynamometry. Respondents were not eligible for testing if they were younger than 6, or had an acute or chronic condition that would likely make grip strength measurement unsafe or the results unreliable or unrepresentative of their usual grip strength.

Grip strength was measured to the nearest kilogram (kg) twice on each hand (alternating) using a Smedley III handgrip dynamometer (Takei Scientific Instruments, Japan). The testing procedure was based on the *Canadian Physical Activity Fitness and Lifestyle Approach (CPAFLA), Third Edition*.[8] Respondents stood with feet slightly apart and the dynamometer held in line with the forearm away from the body at the level of the thigh. They were asked to squeeze the dynamometer as hard as possible, exhaling while squeezing. The highest values attained by each hand were considered the right-hand and left-hand grip strength scores. Maximum grip strength was the highest value attained from either hand, which is less likely than the mean to be affected by the number of trials.[9]

Other measures

Age was self-reported age at the MEC visit. Height was measured to the nearest 0.01 cm using a ProScale M150 digital stadiometer (Accurate Technology Inc., Fletcher, USA). Weight was measured to the nearest 0.01 kg using a Mettler Toldedo VLC with a Panther Plus terminal scale (Mettler Toledo Canada, Mississauga, Canada). Body mass index (BMI) was calculated as kg/m^2.

Statistical analysis

Initially, 16,572 respondents were eligible for grip strength testing. Respondents were excluded from the statistical analysis if they were 80 years old at the time of the MEC visit (n = 2); their grip strength results were outliers based on visual inspection of scatterplots (n = 8); or test results were not obtained for both hands (n = 135). According to previous studies[3,7,10] and preliminary analyses, people with some chronic conditions have significantly lower grip strength compared with their healthy peers. Therefore, respondents were excluded if they had asthma, fibromyalgia, arthritis, high blood pressure (or took medication for high blood pressure in the past month), chronic bronchitis, emphysema, chronic obstructive pulmonary disease, type 2 diabetes or heart disease; ever had a heart attack; had cancer or ever had cancer; suffered from the effects of a stroke; usually walked with difficulty and mechanical support; or were unable to grasp and handle small objects (n = 5,319). This left a final sample of 11,108 (5,438 male; 5,670 female).

All analyses were based on weighted data using the CHMS sample weights for combining cycles 1, 2 and 3.[11] Descriptive statistics were calculated with SAS version 9.3 and SUDAAN version 11. Standard errors, coefficients of variation and 95% confidence intervals were calculated with the bootstrap technique.[12,13] The number of degrees of freedom was specified as 35 to account for the CHMS sample design.[11]

Quantile regression was used to derive reference equations for the 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles of maximum, right-hand and left-hand grip strength for males and females aged 6 to 79. Quantile regression enables estimation of the conditional median and other percentiles, rather than the conditional mean,[14] and produces similar estimates to the LMS method when used to develop growth charts.[15] An advantage of quantile regression is that it does not rely on distributional assumptions, such as normality, and is, therefore, robust to outliers and skewness.[15] Polynomial regression models using different combinations of integer powers of age, height and weight were evaluated using Wald tests, the sum of squared residuals, graphical representation of fitted values, and comparison of fitted and observed percentile values.

Based on the results of these preliminary analyses, grip strength was modeled as a function of age, age^2, height, $height^2$ and weight for males, and as a function of age, age^2, $height^2$ and weight for females. Quantile regression was conducted using the QUANTREG procedure in SAS version 9.3 with the method of confidence interval estimation specified as resampling with 500 repeats.

To examine model fit, graphs were created using three sets of values of the 50th percentile of maximum grip strength at each age. One set of values employed an extension to the World Health Organization (WHO) Growth Charts Adapted for Canada[16] to determine median height and weight by age and sex for 6- to 19-year-olds; for 20- to 79-year-olds, median height and weight were assumed to stay constant. These height and weight values were used in the reference equations to obtain values of grip strength (WHO-fitted values). Another set of values was obtained by calculating the median height and weight, by age and sex, of the study population and using them in the reference equations to obtain grip strength values (CHMS-fitted values). The last

set of values was obtained by calculating the median maximum grip strength of the study population (observed values). The three sets of values were then plotted by age.

To compare maximum, right-hand and left-hand grip strength, values for the 50th percentile were fitted using the WHO growth charts[16] values for median height and weight by age and sex for 6- to 19-year-olds; median height and weight were assumed to stay constant for people aged 20 to 79. Values for maximum, right-hand and left-hand grip strength were plotted by age.

If precision is not required and ease of use is important, a table of reference values may be preferred over calculating person-specific values based on reference equations. Therefore, 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentile reference values for maximum grip strength were calculated using the WHO growth charts[16] values for median height and weight by age and sex for 6- to 19-year-olds, and median height and weight were assumed to stay constant for 20- to 79-year-olds. Reference values were calculated for each year for those aged 6 to 19, and for five-year age groups for those aged 20 to 79.

To compare reference values from this study with those from other coun-

Table 1
Mean and standard deviation of maximum grip strength in kilograms (kg), by sex and age group, healthy household population aged 6 to 79, Canada excluding territories, 2007 to 2013 (combined)

	Total				Males				Females			
		95% confidence interval				95% confidence interval				95% confidence interval		
Age group (years)	Mean (kg)	from	to	Standard deviation	Mean (kg)	from	to	Standard deviation	Mean (kg)	from	to	Standard deviation
Total 6 to 79	**34.5**	**33.9**	**35.0**	**13.2**	**42.8**	**42.1**	**43.5**	**13.0**	**26.2 ****	**25.8**	**26.5**	**6.6**
6 to 11	13.6	13.3	14.0	2.9	14.1	13.6	14.5	2.9	13.2 *	12.8	13.7	2.8
12 to 19	31.2	30.5	31.8	8.0	36.7	35.6	37.7	8.4	25.6 **	25.0	26.1	4.1
20 to 39	38.7	37.9	39.5	14.8	48.5	47.7	49.3	10.3	28.4 **	27.8	29.1	6.0
40 to 59	37.7	36.9	38.5	14.6	47.5	46.3	48.6	9.9	28.2 **	27.6	28.8	6.5
60 to 79	32.3	31.4	33.2	10.2	41.2	40.1	42.3	7.2	24.2 **	23.7	24.7	4.4

* significantly different from males ($p < 0.01$)
** significantly different from males ($p < 0.001$)
Source: 2007 to 2013 Canadian Health Measures Survey (combined).

Table 2
Reference equation coefficients for selected percentiles for maximum, right-hand and left-hand grip strength for ages 6 to 79, by sex, based on a healthy household population, Canada excluding territories, 2007 to 2013 combined

Sex and percentile of grip strength	Grip strength																	
	Maximum						Right hand						Left hand					
	Intercept	Age	Age²	Height	Height²	Weight	Intercept	Age	Age²	Height	Height²	Weight	Intercept	Age	Age²	Height	Height²	Weight
Males																		
5th	53.709	1.123	-0.013	-0.921	0.004	0.076	44.638	1.089	-0.013	-0.806	0.003	0.075	44.683	1.007	-0.012	-0.782	0.003	0.071
10th	50.786	1.098	-0.013	-0.887	0.004	0.078	45.134	1.041	-0.012	-0.818	0.004	0.069	46.105	1.040	-0.012	-0.817	0.003	0.075
25th	53.209	1.061	-0.012	-0.936	0.004	0.091	47.149	0.992	-0.012	-0.858	0.004	0.091	46.588	0.979	-0.011	-0.842	0.004	0.083
50th	50.164	1.076	-0.013	-0.915	0.004	0.100	50.441	1.049	-0.012	-0.924	0.004	0.106	46.955	1.025	-0.012	-0.862	0.004	0.106
75th	40.693	1.058	-0.013	-0.798	0.004	0.139	40.838	1.030	-0.012	-0.802	0.004	0.140	43.449	1.061	-0.013	-0.829	0.004	0.121
90th	35.128	1.092	-0.013	-0.727	0.004	0.170	40.950	1.127	-0.013	-0.815	0.004	0.150	46.441	1.074	-0.013	-0.881	0.004	0.149
95th	35.881	1.083	-0.013	-0.754	0.004	0.172	43.928	1.040	-0.012	-0.871	0.004	0.155	34.059	1.037	-0.012	-0.723	0.004	0.159
Females																		
5th	-8.951	0.478	-0.006	...	0.001	0.038	-9.393	0.448	-0.006	...	0.001	0.030	-8.717	0.437	-0.006	...	0.001	0.022
10th	-9.142	0.443	-0.006	...	0.001	0.046	-9.474	0.447	-0.006	...	0.001	0.042	-8.305	0.475	-0.006	...	0.001	0.031
25th	-8.657	0.435	-0.005	...	0.001	0.060	-9.348	0.420	-0.005	...	0.001	0.053	-8.633	0.435	-0.005	...	0.001	0.051
50th	-9.214	0.453	-0.006	...	0.001	0.069	-9.589	0.453	-0.006	...	0.001	0.065	-8.257	0.455	-0.006	...	0.001	0.063
75th	-8.697	0.483	-0.006	...	0.001	0.088	-8.449	0.485	-0.006	...	0.001	0.093	-8.187	0.455	-0.006	...	0.001	0.083
90th	-8.083	0.499	-0.006	...	0.001	0.118	-8.051	0.508	-0.006	...	0.001	0.110	-8.428	0.507	-0.006	...	0.001	0.100
95th	-7.352	0.555	-0.007	...	0.001	0.128	-7.430	0.556	-0.007	...	0.001	0.126	-7.496	0.555	-0.007	...	0.001	0.113

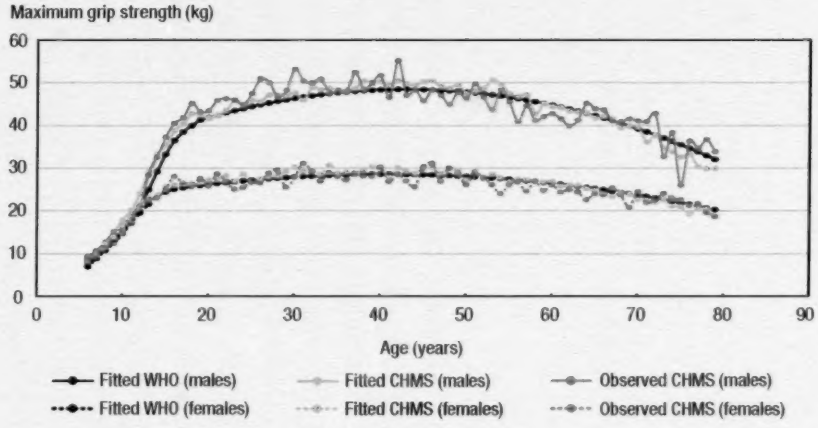
... not applicable
Notes: Age in years, height in centimetres (cm), and weight in kilograms (kg). For example, the 50th percentile maximum grip strength reference value for a 45-year-old man, 180 cm tall who weighs 90 kg, maximum grip strength = 50.164 + (1.076 * (45)) + (-0.013* (45*45)) + (-0.915 * (180)) + (0.004 (180*180)) + (0.100* (90))
Source: 2007 to 2013 Canadian Health Measures Survey (combined).

tries, values for the 50th percentile for maximum grip strength were fitted using the WHO growth charts[16] as described above. Although reference values for other countries were available from a large number of studies, only four were selected for comparison,[17-20] based on sample size, a wide age range, representativeness, measurement of grip strength in kilograms or pounds, and date of publication. Multiple studies were not selected from the same country. For studies presenting reference values by right and left hand, the right-hand values were selected for comparison. For studies presenting reference values by age group, the age in the middle of the range was selected as the data point. Values were then plotted by age.

Results

The mean age of the study population was 35.1 years (95% CI: 34.6 to 35.6)

Figure 1
Median grip strength (in kilograms) for observed and fitted population, by age, sex and source of fitted data, Canadian reference equations for the healthy population aged 6 to 79



Notes: Fitted World Health Organization (WHO) = based on reference equations fit with median height and weight from World Health Organization Growth Charts Adapted for Canada[16]
Fitted Canadian Health Measures Survey (CHMS) = based on reference equations fit with median height and weight from a healthy household population aged 6 to 79, Canada excluding territories, 2007 to 2013
Observed CHMS = healthy household population aged 6 to 79, Canada excluding territories, 2007 to 2013
Source: 2007 to 2013 Canadian Health Measures Survey (combined).

Table 3
Reference values for selected percentiles for maximum grip strength (in kilograms), by sex and age, based on reference equations for Canadians aged 6 to 79

	Maximum grip strength													
	Males							Females						
	Percentile							Percentile						
Age (years)	5th	10th	25th	50th	75th	90th	95th	5th	10th	25th	50th	75th	90th	95th
6	5.3	5.9	7.0	8.0	9.0	10.1	10.7	4.2	4.7	5.9	6.9	8.4	9.7	10.6
7	6.2	7.0	8.3	9.6	11.0	12.4	13.1	5.7	6.3	7.6	8.8	10.4	11.8	12.7
8	7.4	8.3	9.7	11.3	13.0	14.7	15.6	7.3	7.9	9.3	10.7	12.4	13.9	14.9
9	8.9	9.9	11.5	13.4	15.5	17.4	18.4	8.7	9.5	10.9	12.5	14.3	16.0	17.0
10	10.3	11.5	13.3	15.4	17.7	19.8	21.0	10.4	11.2	12.8	14.6	16.5	18.3	19.3
11	12.3	13.6	15.6	18.1	20.8	23.2	24.6	12.4	13.3	15.0	17.1	19.1	21.0	22.1
12	14.4	15.9	18.2	21.0	24.1	26.7	28.4	14.2	15.3	17.2	19.5	21.7	23.8	24.9
13	17.3	18.9	21.6	24.9	28.4	31.3	33.3	15.9	17.0	19.0	21.5	24.0	26.2	27.4
14	20.5	22.3	25.5	29.1	33.1	36.3	38.6	17.3	18.5	20.6	23.3	25.8	28.2	29.4
15	23.6	25.6	29.1	33.2	37.4	41.0	43.5	18.2	19.4	21.6	24.4	27.0	29.4	30.7
16	26.1	28.2	32.1	36.4	40.9	44.7	47.4	18.7	20.0	22.2	25.0	27.7	30.2	31.6
17	27.8	30.0	33.9	38.4	43.1	47.0	49.8	19.0	20.3	22.5	25.3	28.0	30.6	32.0
18	29.1	31.3	35.3	39.9	44.7	48.7	51.6	19.3	20.6	22.8	25.6	28.4	30.9	32.3
19	30.3	32.5	36.6	41.2	46.1	50.2	53.2	19.6	20.8	23.0	25.9	28.7	31.3	32.7
20 to 24	32.0	34.2	38.2	42.9	47.7	51.9	54.8	20.2	21.5	23.7	26.6	29.4	32.0	33.5
25 to 29	34.3	36.5	40.5	45.2	49.9	54.2	57.1	21.1	22.3	24.6	27.5	30.3	32.9	34.6
30 to 34	35.9	38.2	42.1	46.9	51.5	55.8	58.7	21.7	22.9	25.2	28.1	31.0	33.6	35.3
35 to 39	36.9	39.2	43.2	47.9	52.5	56.8	59.7	22.0	23.2	25.5	28.4	31.3	34.0	35.7
40 to 44	37.2	39.7	43.6	48.4	52.9	57.2	60.0	21.9	23.2	25.6	28.5	31.4	34.0	35.8
45 to 49	36.9	39.4	43.4	48.1	52.6	56.9	59.7	21.6	23.0	25.4	28.3	31.1	33.7	35.5
50 to 54	35.9	38.5	42.5	47.3	51.7	56.0	58.8	21.0	22.5	25.0	27.8	30.5	33.1	34.9
55 to 59	34.2	37.0	41.1	45.9	50.1	54.4	57.2	20.0	21.7	24.2	27.0	29.7	32.2	33.9
60 to 64	31.8	34.9	39.0	43.8	48.0	52.1	55.0	18.7	20.6	23.3	25.9	28.5	31.0	32.6
65 to 69	28.8	32.1	36.3	41.1	45.2	49.2	52.1	17.2	19.2	22.0	24.6	27.1	29.5	30.9
70 to 74	25.1	28.6	33.0	37.7	41.8	45.7	48.6	15.3	17.6	20.5	23.0	25.3	27.7	28.9
75 to 79	20.7	24.5	29.1	33.7	37.8	41.5	44.4	13.1	15.7	18.7	21.1	23.3	25.5	26.6

Note: Reference equations fit with median height and weight from World Health Organization Growth Charts Adapted for Canada.[16]
Source: 2007 to 2013 Canadian Health Measures Survey (reference equations).

for males and 36.0 years (95% CI: 35.5 to 36.6) for females. Mean BMI was 25.7 (95% CI: 25.4 to 26.0) for males and 26.0 (95% CI: 25.5 to 26.5) for females. Males' maximum grip strength significantly exceeded that of females: 42.8 versus 26.2 kg (Table 1).

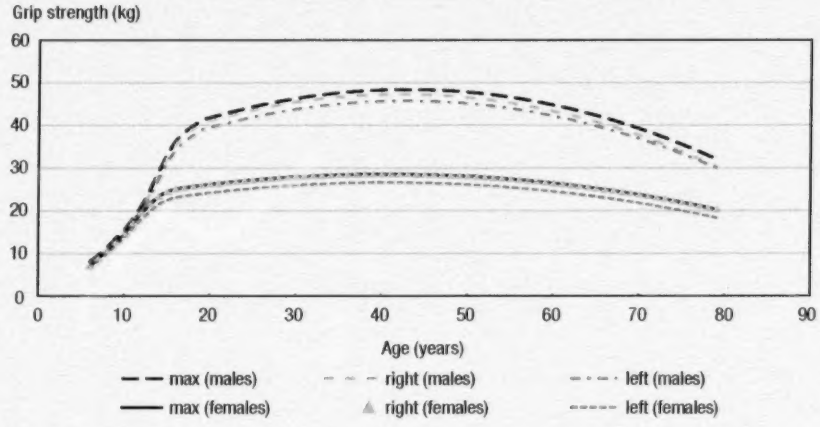
Coefficients for the reference equations for the 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles of maximum, right-hand and left-hand grip strength are shown in Table 2. Reference values based on these equations are presented by age in Table 3. A comparison of reference values based on fitted values using the WHO growth charts,[16] and the CHMS study population with observed median values of maximum grip strength is shown in Figure 1.

Grip strength increased from childhood through adolescence, peaked in the 35-to-45 age range for men and in the 30-to-50 age range for women, and then decreased. Differences in grip strength between males and females were smaller during childhood than in adolescence and adulthood.

Fitted values for the 50th percentile were compared for maximum, right-hand and left-hand grip strength (Figure 2). Among women, the right hand tended to be stronger; among men, this tendency was less pronounced. Among children, right- and left-hand grip strength were similar.

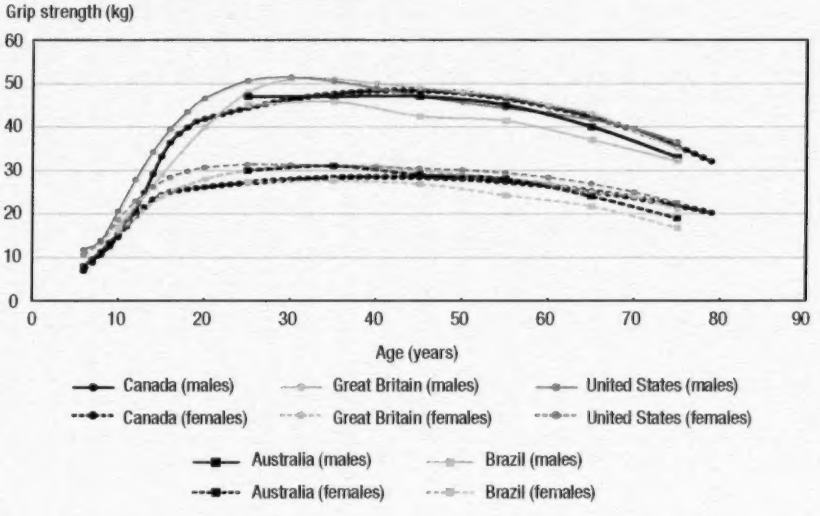
WHO-fitted values for the 50th percentile of maximum grip strength were compared with the results for four other countries[17-20] (Figure 3). Norms for males in the United States[7] and Great Britain[18] increased from childhood to peak around age 30, and then decreased. The CHMS norms increased more steeply through adolescence, but thereafter, rose less sharply and peaked around age 40. The CHMS norms were among the lowest for 20- to 30-year-olds, but among the highest for people aged 40 or older. Trends for females were generally similar, except the CHMS norms did not increase more sharply through adolescence than did norms from other studies.[17-20]

Figure 2
Maximum, right-hand and left-hand grip strength (in kilograms), by age and sex, based on reference 50th percentile equations for Canadians aged 6 to 79



Note: Reference equations were fit with median height and weight values from World Health Organization Growth Charts Adapted for Canada.[16]
max = maximum grip strength
right = right-hand grip strength
left = left-hand grip strength
Source: 2007 to 2013 Canadian Health Measures Survey (reference equations).

Figure 3
Mean/Median grip strength reference values (in kilograms) for selected countries, by age and sex, selected years, 2007 to 2015



Sources: Canada (2007 to 2013 Canadian Health Measures Survey); Great Britain[18]; United States[17]; Australia[19]; Brazil.[20]

Discussion

With data from the 2007-to-2013 CHMS, grip strength reference equations were developed for Canadians aged 6 to 79. These equations can be used to compare an individual's measured grip strength with the predicted 5th, 10th, 25th, 50th, 75th, 90th and 95th percentiles of grip strength for healthy individuals of the same age, sex, height and weight. Unlike previous reference values, these equations range from childhood to older adulthood and were based on a large, healthy, nationally representative sample.

Patterns of grip strength norms through the life course for males and females were consistent with others studies.[2,17,18] Males were stronger than females, although differences were smaller during childhood than in adolescence and adulthood.

The relationship with age was curvilinear. Grip strength increased from childhood through adolescence, peaked in mid-adulthood, and then declined. The age at which grip strength peaked varied among studies. The CHMS norms for men were highest at ages 40 to 44, which is within the range of 20 to 49 reported by Massey-Westropp et al.,[19] and slightly older than the ages of 30,[17] 30 to 39[20] and 29 to 39[18] reported elsewhere. For women, the CHMS norms were highest at ages 30 to 49, which is similar to studies reporting peaks between ages 30 to 39[19,20] and ages 26 to 42,[18] but slightly older than the 25-to-30 age range reported by others.[18]

WHO-fitted values and CHMS-fitted values were close to observed median values of maximum grip strength. The values were most similar for children, and generally more similar for females than for males. Observed values varied more from one age to the next for males than for females. For male adolescents, the WHO-fitted values were slightly lower than the CHMS-fitted and observed values. This suggests that the median height and weight of the healthy adolescents in this study slightly exceeded the median height and weight of the WHO growth charts.[16] For men, the WHO-fitted values were somewhat lower than observed values from ages 20 to 40 and somewhat higher than observed values from ages 40 to 60. The WHO-fitted values were also a little higher than the CHMS-fitted values for those aged 70 or older. These differences may be partly due to the use of a fixed value for height and weight throughout adulthood for the WHO-fitted values, and suggest that median height and weight varied by age for the adults in this study. However, overall, the reference equations fit the observed grip strength measurements relatively well.

Results of the comparison between norms for maximum, right-hand and left-hand grip strength were consistent with earlier research.[21] For the vast majority of right-hand-dominant people, the right hand tends to be stronger than the left. By contrast, for a substantial percentage of left-hand-dominant people, the right hand is stronger.[21] The difference in strength between hands tends to be greater for those who are right-handed.[22] Men are also slightly more likely than women to be left-handed.[23] Thus, it would be expected that maximum grip strength norms more closely resemble those for the right hand than the left, particularly among women.

While it may be more accurate to present norms by both side and hand dominance, because approximately 90% of people are right-handed,[24] sample sizes have tended to be insufficient to do so.[19,25,26] Therefore, norms have been published for the right hand and the left hand, or for dominant and non-dominant hand, but not for side and dominance together. Hand dominance was not determined in the CHMS, so norms are presented by side. If a specific hand is of interest, such as assessing the outcome of hand surgery, separate norms for each hand may be helpful. However, in most cases, use of maximum grip strength norms avoids the inaccuracy associated with norms presented by side or hand dominance.

When the 50th percentile reference equation was fitted with data from the WHO growth charts,[16] the values were within the range of other norms.[17-20] Differences may be partly attributable to the norms being based on data from the United States,[17] Great Britain,[18] Australia,[19] and Brazil.[20] Previous research[2] has also noted differences in norms between countries, which supports the notion that norms should be country-specific.

Differences among norms may also reflect the composition of study samples. The present study excluded respondents who had chronic or other conditions that would affect grip strength. By contrast, Peterson and Krishnan[17] and Dodds et al.[18] did not exclude respondents to obtain a healthy sample. Massy-Westropp et al.[19] and Schlussel et al.[20] excluded respondents with conditions such as hand pain and osteoarthritis, but the exclusion criteria were not as strict as those applied in this study. The higher prevalence of chronic conditions such as heart disease, type 2 diabetes and chronic obstructive pulmonary disease at older

What is already known on this subject?

- Grip strength is a measure of overall muscular strength and has been associated with disability, morbidity and mortality.
- Normative data are used to interpret an individual's grip strength measurements, but reference values for a wide age range of the Canadian population are not available.

What does this study add?

- Based on a large sample of nationally representative data, reference equations for grip strength were developed for Canadians from childhood to older adulthood.
- These equations can be used to determine the reference values for a person of a given age, sex, height and weight.

ages may explain why the WHO-fitted values for the CHMS were higher than for the other norms at age 40 or older.

Another difference is the manner in which the norms were derived. Peterson and Krishnan[17] and Dodds et al.[18] modelled grip strength as a function of age, whereas Massy-Westropp et al.[19] and Schlussel et al.[20] calculated mean grip strength from the sample population. The CHMS reference equations were a function of age, height and weight. Median height and weight values from the WHO growth charts[16] were used to fit values that could be graphed for comparison with other norms. Thus, the resulting values do not represent the 50th percentile of the entire Canadian population, but rather, the 50th percentile of a healthy Canadian population with the median height and weight from the WHO growth charts.[16] Median grip strength values of the entire Canadian population would vary to the extent that height and weight differ from these values, and from the inclusion of people with chronic and other conditions that influence grip strength.

Testing position affects the results of grip strength tests. The position recommended by the American Society of Hand Therapists (ASHT) requires being seated with the elbow flexed to 90°.[27] By contrast, the CHMS measured grip strength according to the CPAFLA protocol that specifies standing with the elbow being extended. Standing results in higher grip strengths than does sitting, but studies of the effect of elbow position have been inconsistent.[2] Although many studies adopted the ASHT's recommended testing position, many others did not.[2] The testing position in the CHMS is consistent with that used in previous national surveys[17,28] and is recommended by the Canadian Society for Exercise Physiology for fitness assessments.[8]

The reference equations developed in this study apply only to people aged 6 to 79. This is a limitation, particularly given the interest in the clinical and prognostic value of grip strength for older adults.[1,5] Deriving reference equations that include children younger than 6 and seniors older than 79 would require additional grip strength data collected using similar dynamometers and test protocols.

Normative values enable comparisons of grip strength relative to a reference population. This study presents reference equations and values for percentiles ranging from the 5th to the 95th percentiles, which is consistent with other studies.[17,18] The 5th percentile has been proposed as a point of reference for abnormally low grip strength.[29] However, future studies are needed to establish its clinical relevance and prognostic value.

Conclusion

Data from the 2007-to-2013 CHMS made it possible to develop grip strength reference equations for Canadians aged 6 to 79. These equations can be used to compare an individual's grip strength measurements to the predicted grip strength of a healthy individual of the same age, sex, height and weight. Unlike previous reference values, these reference equations were based on a large, nationally representative sample of healthy 6- to 79-year-olds.

References

1. Bohannon RW. Muscle strength: clinical and prognostic value of hand-grip dynamometry. *Current Opinion in Clinical Nutrition and Metabolic Care* 2015; 18: 465-70.
2. Innes E. Handgrip strength testing: A review of the literature. *Australian Occupational Therapy Journal* 1999; 46: 120-40.
3. Mainous III AG, Tanner RJ, Anton SD, Jo A. Grip strength as a marker of hypertension and diabetes in healthy weight adults. *American Journal of Preventive Medicine* 2015; 49(6): 850-8.
4. Leong DP, Teo KK, Rangarajan S, et al. Prognostic value of grip strength: findings from the Prospective Urban Rural Epidemiology (PURE) study. *Lancet* 2015; 386: 266-73.
5. Bohannon RW. Hand grip dynamometry predicts future outcomes in aging adults. *Journal of Geriatric Physical Therapy* 2008; 31: 3-10.
6. Mathiowetz V, Kashman N, Volland G, et al. Grip and pinch strength: normative data for adults. *Archives of Physical Medicine and Rehabilitation* 1985; 66: 69-72.
7. Yorke AM, Curtis AB, Shoemaker M, Vangsnes E. Grip strength values stratified by age, gender, and chronic disease status in adults aged 50 years and older. *Journal of Geriatric Physical Therapy* 2015; 38: 115-21.
8. Canadian Society for Exercise Physiology. *Canadian Physical Activity, Fitness and Lifestyle Approach (CPAFLA), Third Edition.* Ottawa: Canadian Society for Exercise Physiology, 2003.
9. Roberts HC, Denison HJ, Martin HJ, et al. A review of the measurement of grip strength in clinical and epidemiological studies: towards a standardised approach. *Age and Ageing* 2011; 40: 423-9.
10. Cortopassi F, Divo M, Pinto-Plata V, Celli B. Resting handgrip force and impaired cardiac function at rest and during exercise in COPD patients. *Respiratory Medicine* 2011; 105: 748-54.
11. Statistics Canada. *Instructions for Combining Multiple Cycles of Canadian Health Measures Survey (CHMS) Data.* Statistics Canada: Ottawa, 2015.
12. Rao JNK, Wu CFJ, Yue K. Some recent work on resampling methods for complex surveys. *Survey Methodology* (Statistics Canada, Catalogue 12-001) 1992; 18(2): 209-17.
13. Rust KF, Rao JNK. Variance estimation for complex surveys using replication techniques. *Statistical Methods in Medical Research* 1996; 5(3): 283-310.

14. Koenker R, Bassett G. Regression quantiles. *Econometrica* 1978; 46: 33-50.

15. Wei Y, Pere A, Koenker R, He X. Quantile regression methods for reference growth charts. *Statistics in Medicine* 2006; 25: 1369-82.

16. Lawrence S, Cummings E, Chanoine JP, et al. Canadian Pediatric Endocrine Group extension to WHO growth charts: why bother? *Paediatrics and Child Health* 2013; 18: 295-7.

17. Peterson MD, Krishnan C. Growth charts for muscular strength capacity with quantile regression. *American Journal of Preventive Medicine* 2015; published online ahead of print.

18. Dodds RM, Syddall HE, Cooper R, et al. Grip strength across the life course: normative data from twelve British studies. *PLoS ONE* 2014; 9(12): e113637. doi: 10.1371/journal.pone.0113637.

19. Massy-Westropp NM, Gill TK, Taylor AW, et al. Hand grip strength: age and gender stratified normative data in a population-based study. *BMC Research Notes* 2011; 4: 127.

20. Schlussel MM, dos Anjos LZ, de Vasconcellos MTL, Kac G. Reference values of handgrip dynamometry of healthy adults: a population-based study. *Clinical Nutrition* 2008; 27: 601-7.

21. Bohannon RW. Grip strength: a summary of studies comparing dominant and nondominant limb measurements. *Perceptual and Motor Skills* 2003; 96: 728-30.

22. Peterson P, Petrick M, Connor H, Conklin D. Grip strength and hand dominance: challenging the 10% rule. *American Journal of Occupational Therapy* 1989; 43: 444-7.

23. Papadatou M, Martin M, Munafo MR, Jones GV. Sex differences in left-handedness: a meta-analysis of 144 studies. *Psychological Bulletin* 2008; 134: 677-99.

24. Oldfield R. The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia* 1971; 9: 97-113.

25. Puh U. Age-related and sex-related differences in hand and pinch grip strength in adults. *International Journal of Rehabilitation Research* 2010; 33: 4-11.

26. Budziareck MB, Duarte RRP, Barbosa-Silva MC. Reference values and determinants for handgrip strength in healthy subjects. *Clinical Nutrition* 2008; 27: 357-62.

27. Fess EE. Grip strength. In: Cassonova JS, ed. *Clinical Assessment Recommendations. Second Edition.* Chicago: American Society of Hand Therapists, 1992: 41-5.

28. Stephens, T, Craig, CL. Fitness and activity measurement in the 1981 Canada Fitness Survey. In: Drury T, ed. *Assessing Physical Fitness and Activity Patterns in General Population Surveys.* Pub. No. (PHS) 89-1253. Hyattsville, Maryland: National Center for Health Statistics, 1989.

29. Spruit MA, Sillen MJH, Groenen MTJ, et al. New normative values for handgrip strength: results from the UK Biobank. *Journal of the American Medical Directors Association* 2013; 775.e5-775.e11.